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Continued Water-Based Phase Change Heat Exchanger Development

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Overview

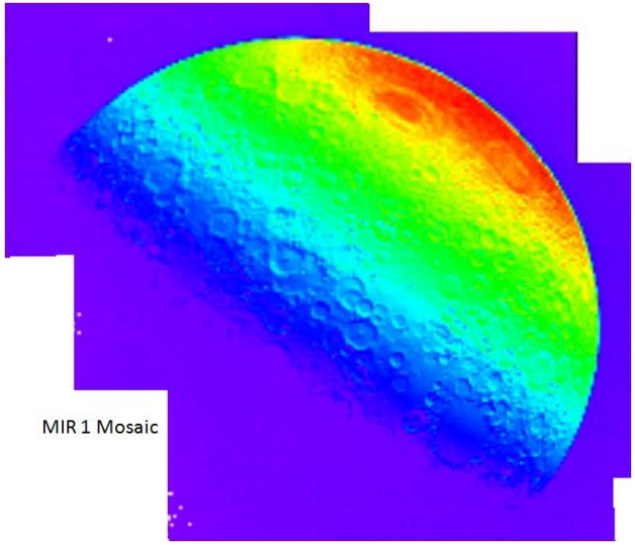
- Why use Phase Change Material Heat Exchanger's (PCM HX's)?
- Prior PCM HX Development and Testing
- Full-Scale Design
- Prototypic Freezing and Thawing
- Unit A and Unit B Testing Summary
- Subscale Design and Testing Summary

WHY USE A WATER-BASED PCM HX?

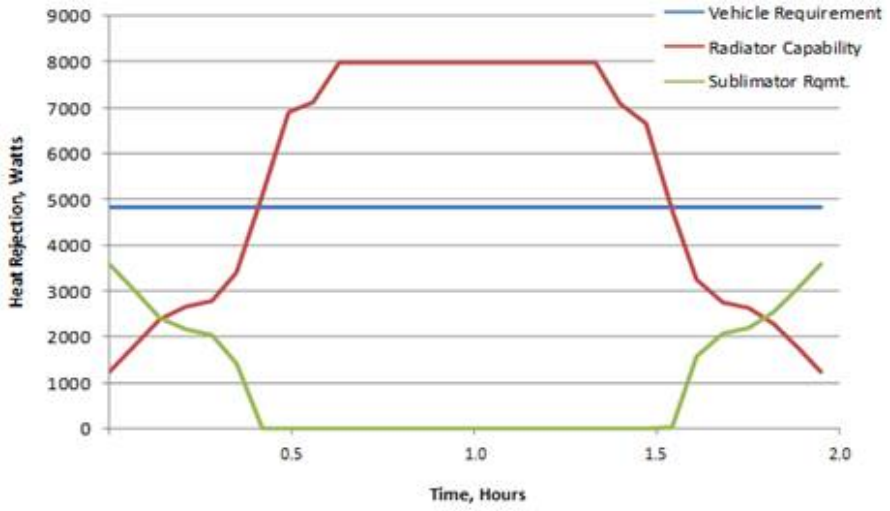
Why Use Water as a PCM?

- In cyclical heat load environments, a Supplemental Heat Rejection Device (SHReD) is required
  - Typically, accomplished through evaporators, sublimators, or Phase Change Material Heat Exchangers (PCM HX)
  - PCM's act a thermal battery and do not use a consumable
- Wax PCM is baseline for the Orion Spacecraft, but water is being investigated
  - Water has significantly higher latent heat of fusion than wax (333 kJ/kg vs. 163 kJ/kg)
  - Significant mass and volume savings possible

Problem: Water expands ~10% when frozen



LCROSS IR Image of Lunar Surface

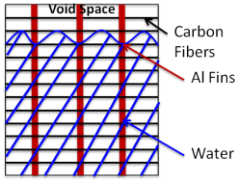


PRIOR PCM HX DEVELOPMENT AND TESTING

Why Use Water as a PCM?

PCM HX Development

- Energy Sciences Laboratory
- Bench-Top Testing
- Mezzo Technologies



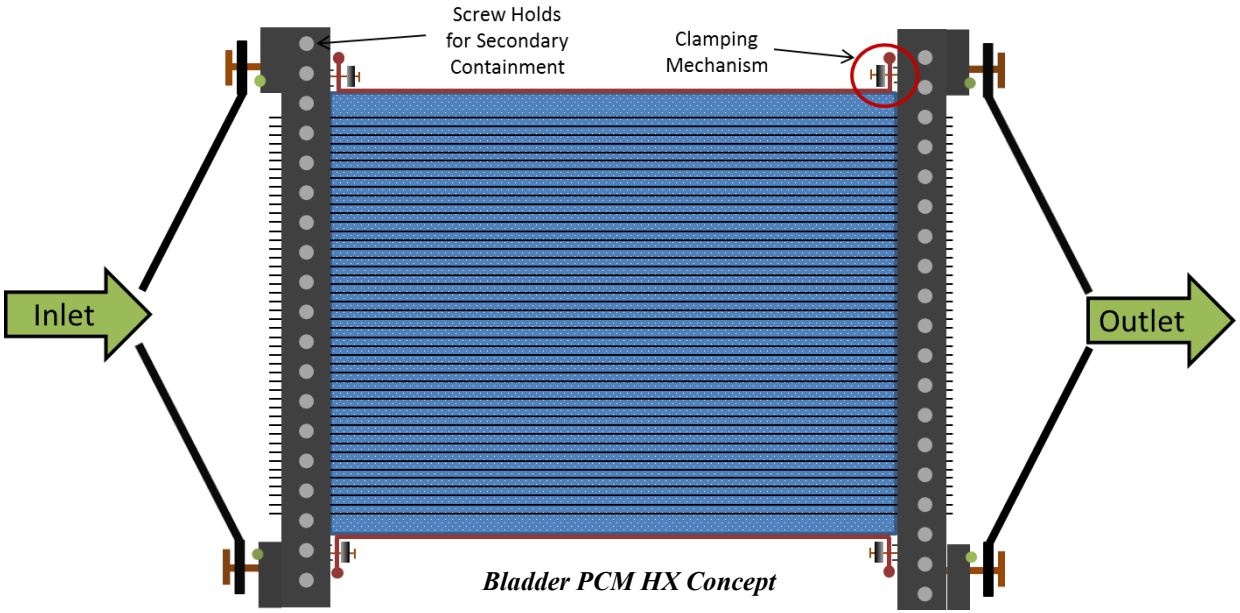
Ice Spike Formation Comparison in SHRIMP

Copper Coupon

Mezzo Technology HX

Learning Outcomes from Historical Testing

- Providing extra void space may not necessarily lead to the development of a successful HX as void space will not necessarily be known in microgravity
- Use of “ice spike distribution” through inside-out freezing or uniform freezing should be pursued for future development
- Use of a bladder is feasible to implement with a water-based PCM HX

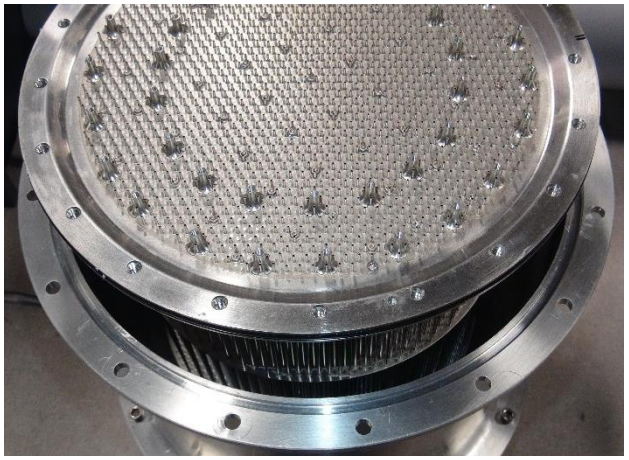


Bladder PCM HX Concept

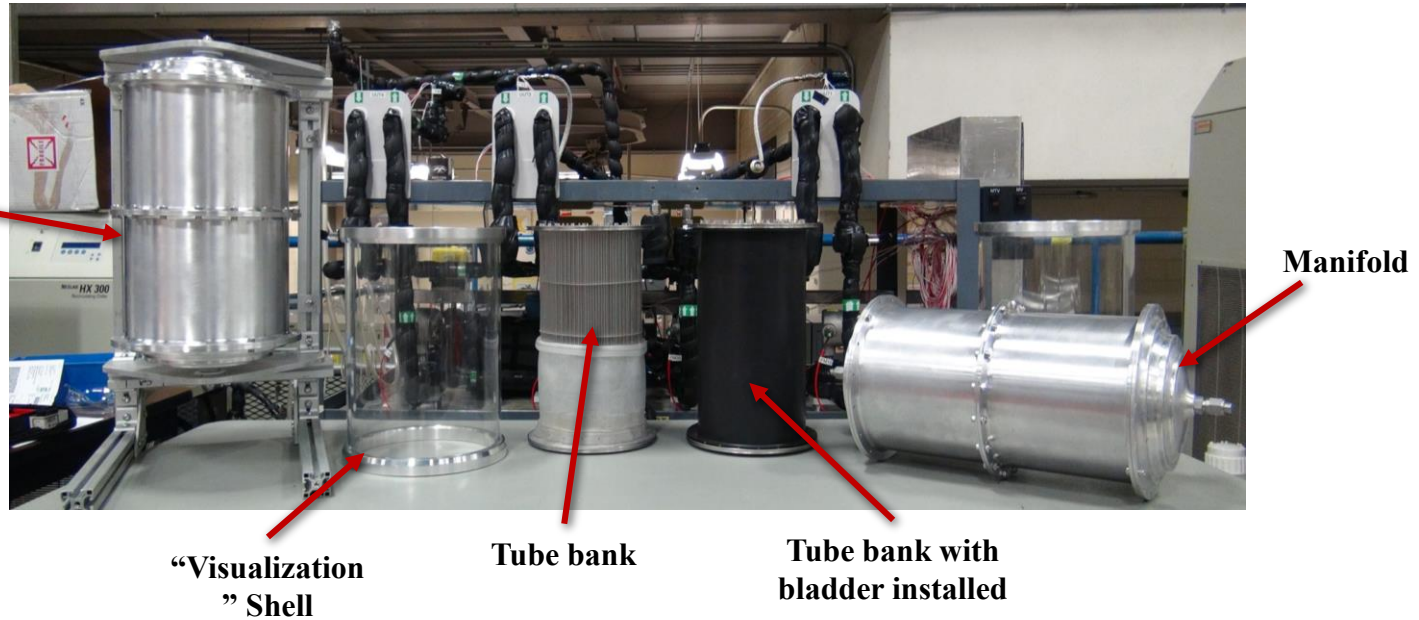
FULL-SCALE DESIGN AND DEVELOPMENT

Full-Scale Design and Development

- 2 Orion-like full-scale PCM HX were designed and constructed through a SBIR Phase II with Mezzo Technologies
  - 3,700 kJ energy storage
- Each unit consists of 3 main components
  - Tube bank
  - Manifolds
  - Metal or “visualization” shell
- 12 kg of metal and 11.1 kg water
- Thermal analysis from Mezzo showed that it is possible to freeze/thaw in 90/30 minutes given sink temperatures and associated PCM inlet temperatures and flow rates

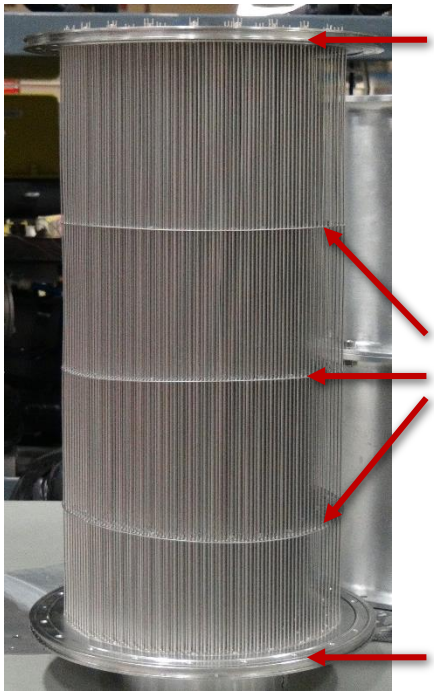


Tube Bank Being Installed into Shell

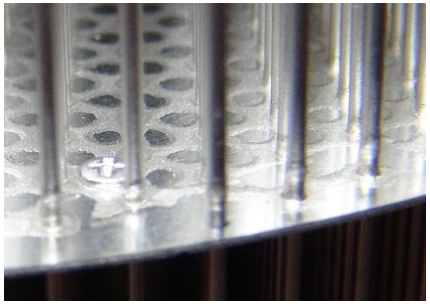


Full-Scale Design and Development (Cont.)

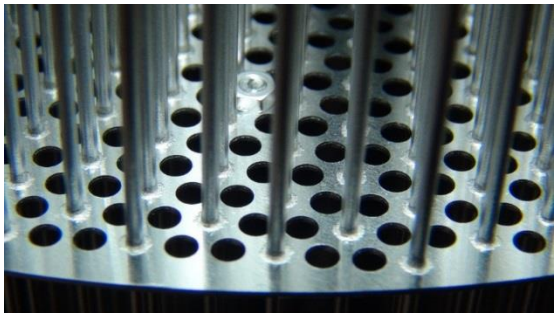
- Tube bank consists of 1,420 tubes
  - OD 0.042”, ID0.035”, wall thickness 0.0035”
  - 10% greater concentration in the center
  - Tubes brazed to tube sheets and midplates
- 2 Units constructed (EDU A & EDU B)
  - Units are essentially identically differing only by their midplate
  - Unit A: No holes in midplate
  - Unit B: Holes in midplate
- Viton GLT bladder manufactured through injection molding



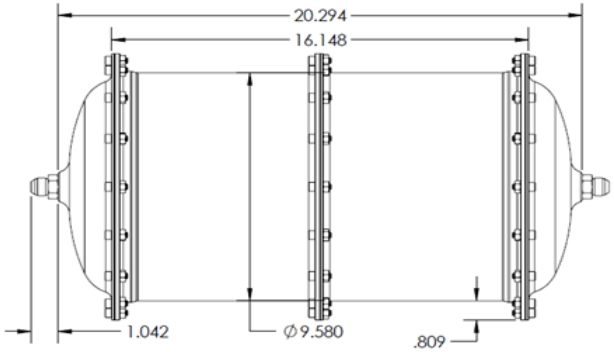
Tube Bank

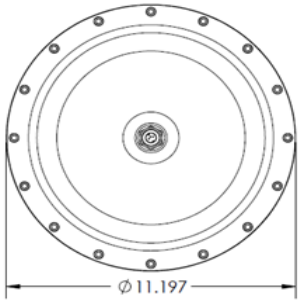


Unit A Midplate Design



Unit B Midplate Design

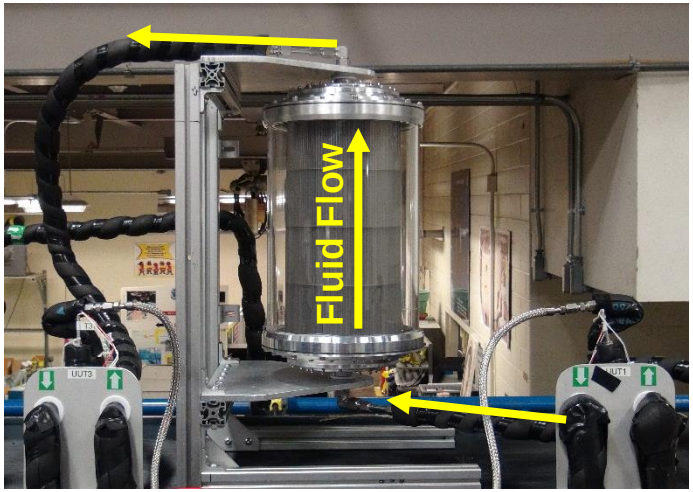




PROTOTYPIC FREEZING AND THAWING

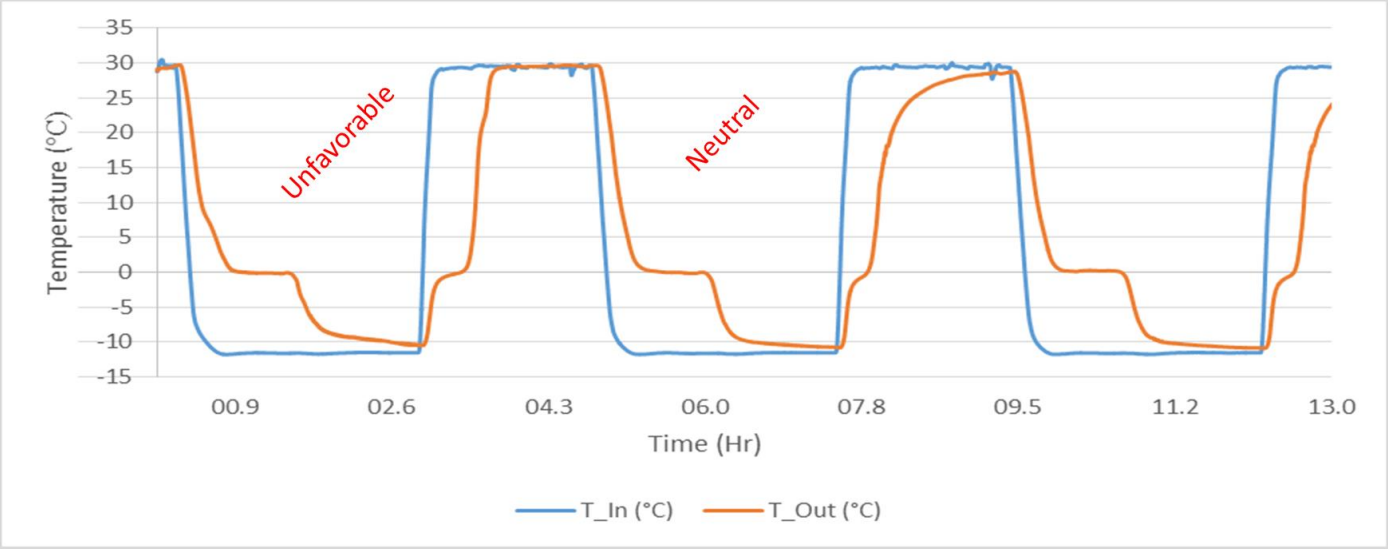
Test Set-Up

- Tested on RIP test stand at JSC
- 3 orientations tested
  - Favorable, unfavorable, neutral
- 50/50 PGW used as a working fluid with inlet and outlet temperatures of -12C to 30C controlled by chiller carts
- Transient testing also tested
- Bladder filled 100% with degassed water and 0% void space
- Goal was to achieve 100 cycles without failure



Favorable Testing Fluid Flow

Normal Freeze/Thaw Cycle Profiles



Test Set-Up

- Bulge near outlet was expected to be observed during freezing but no bulge occurred
  - Due to bladder flexibility
  - Max expansion of ~1/2" (estimated at ¾")
  - Midplates did not have a noticeable effect on ice spike formation

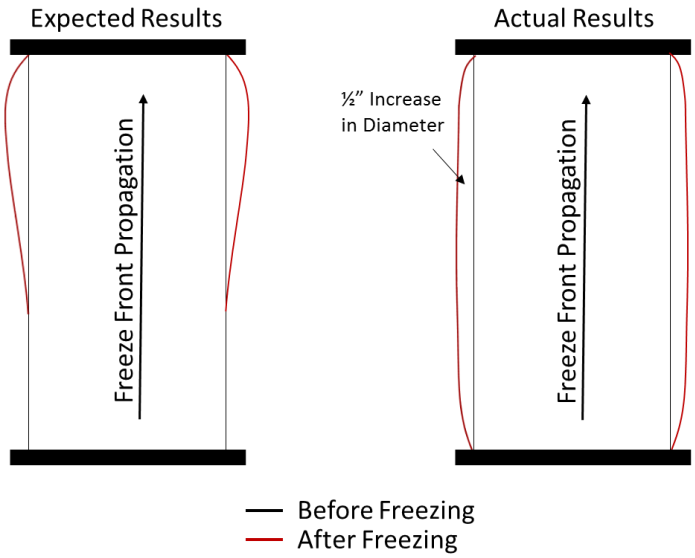


Image Comparison: Favorable

Image Comparison: Unfavorable

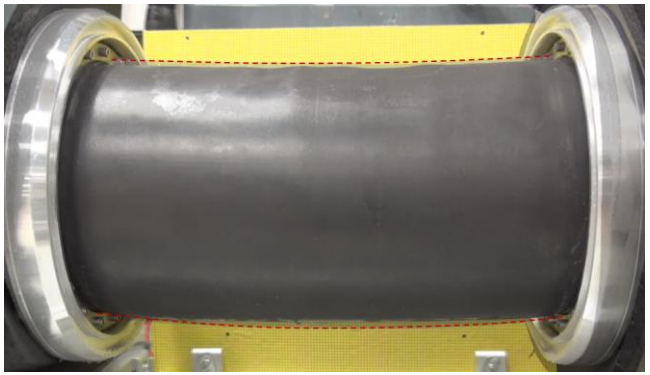


Image Comparison: Neutral

Prototypic Thaw Cycle

- Thawing did not occur as predicted
  - Hypothesized that bladder would simply return to its original position,
  - Bladder was pressed against tube bank because of decreased internal pressure due to melting water and corresponding decrease in volume
  - Caused significant bending in tubes around perimeter of the HX

Fully Frozen

10 min

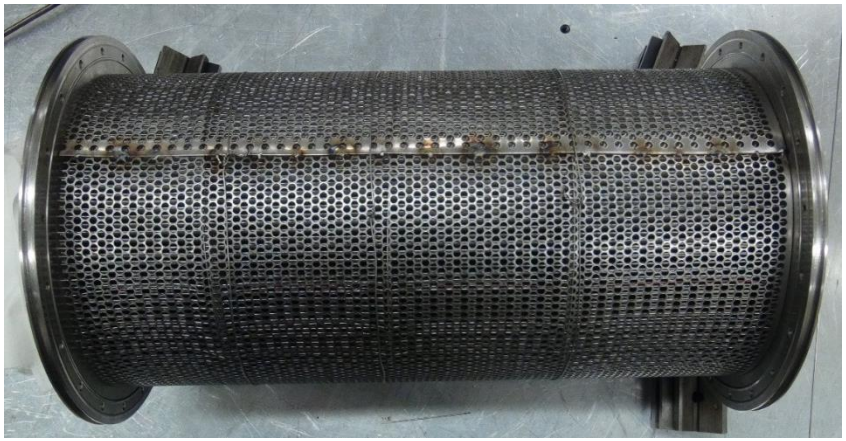
15 min

25 min

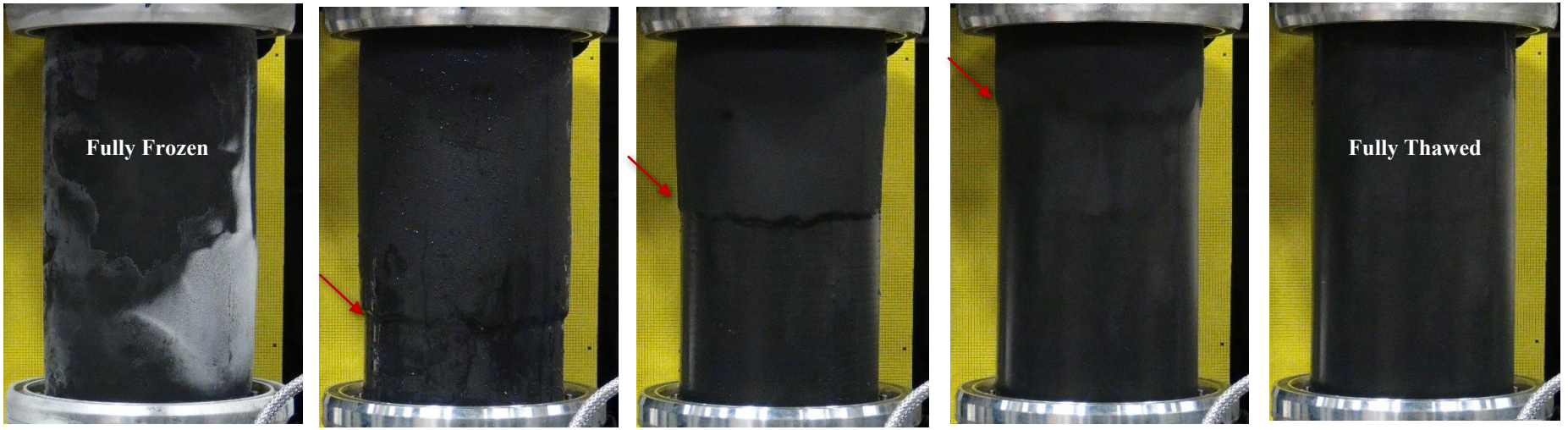
Unit A Bent Tubes Post-Test

Perforated Sheet Addition

- To prevent tubes around the perimeter of the HX from bladder compression, a stainless steel perforated sheet was cut, rolled, and spot welded onto the tube bank core
- Testing resumed after sheet was in place



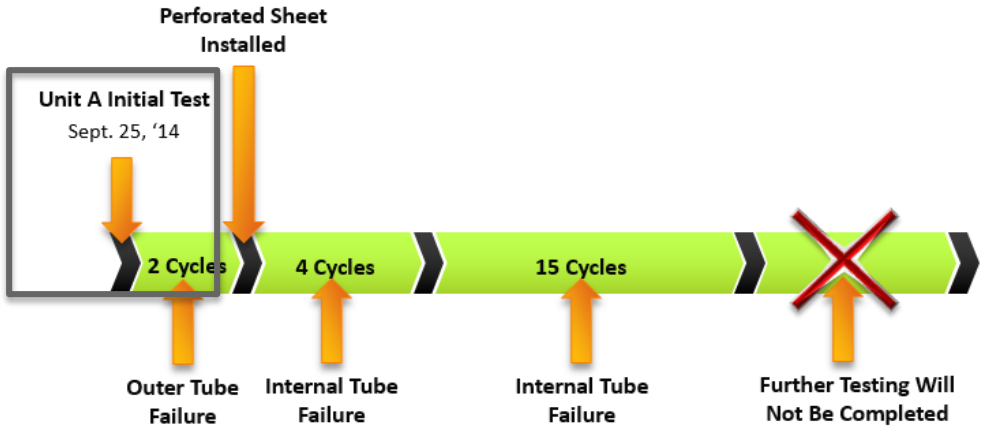
Perforated Sheet Installed



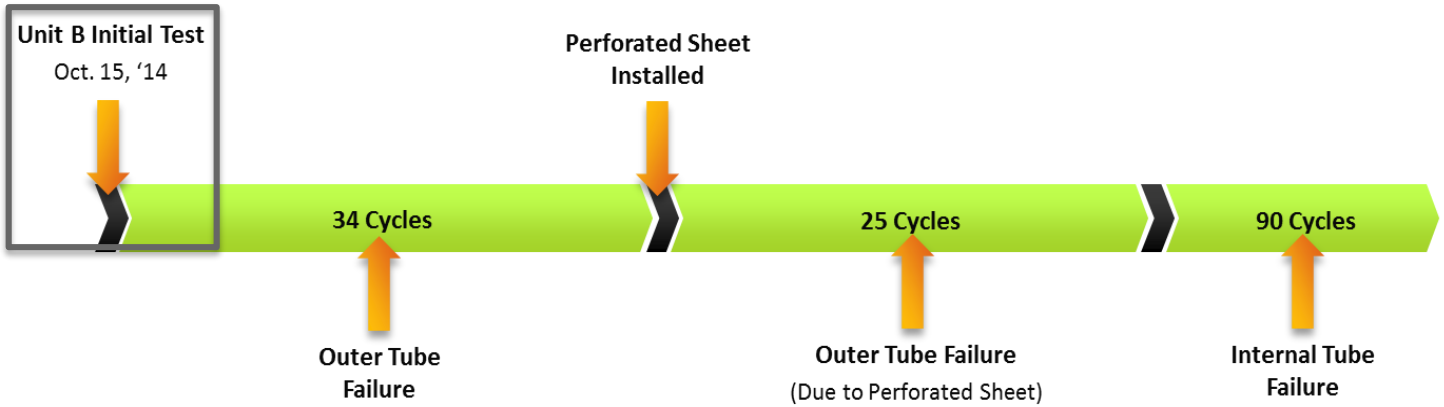
Thawing Progression with Perforated Sheet Installed

UNIT A AND UNIT B TESTING SUMMARY

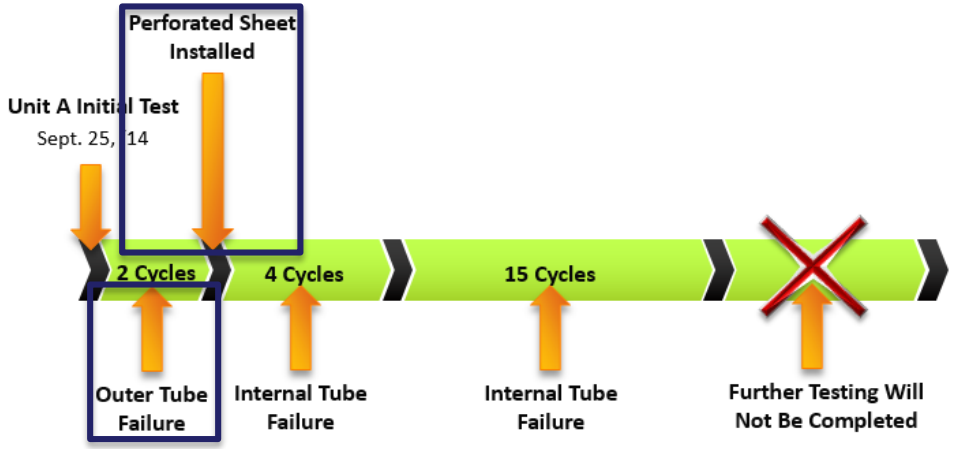
EDU A&B Testing Summary

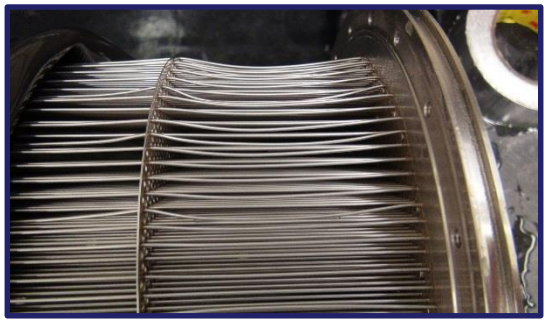


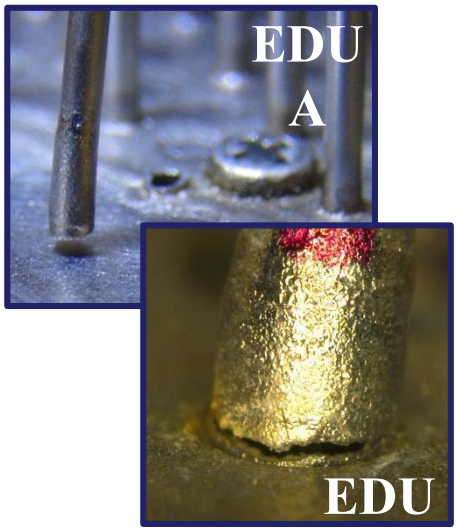
- **Freeze and thaw tests were done on both EDUs with the Viton® bladder**
  - **Upon freezing the unit, the ice caused the bladder to expand as expected**
  - **Upon thawing, the bladder compressed onto the tubes due to the contraction of the water**



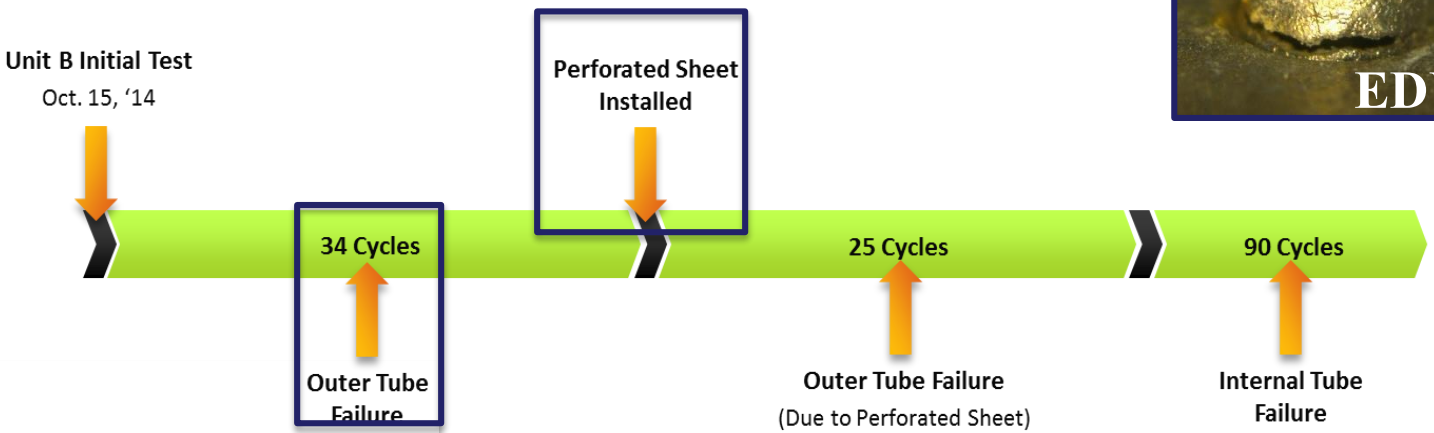
EDU A&B Testing Summary



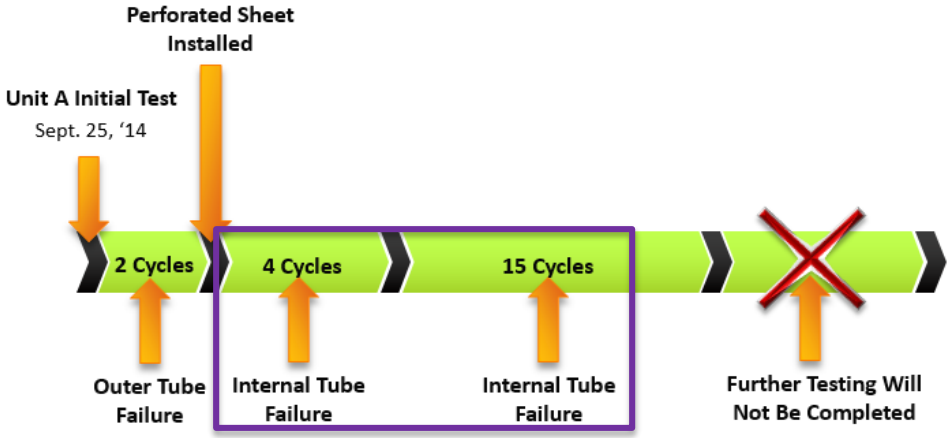


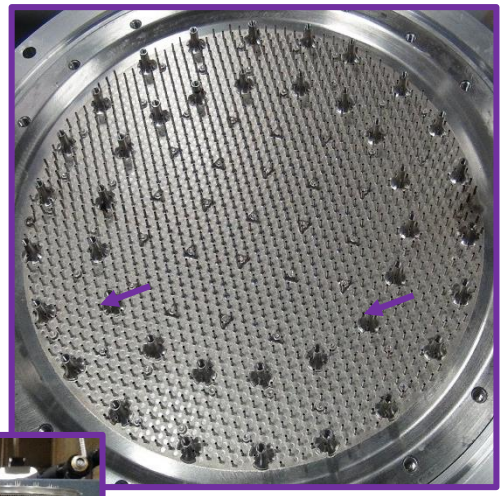


- Due to multiple compressions cycles of the bladder on to the perimeter tubes, a failure of an outside tube eventually occurred on both units
- A perforated sheet was wrapped around the tube core of the HX to protect from the compression

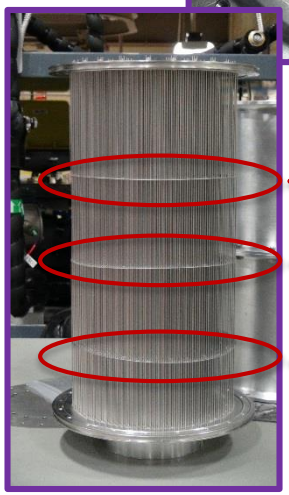


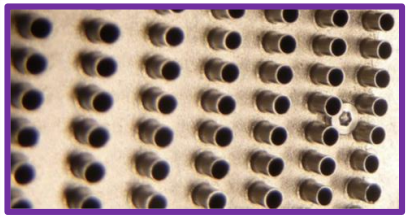
EDU A&B Testing Summary





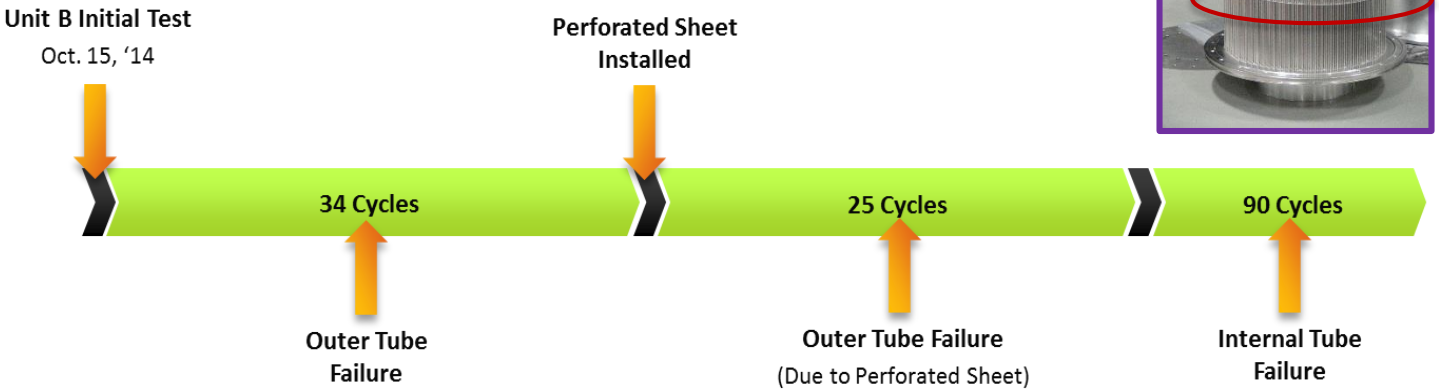
- Two internal tubes failed on EDU A
  - EDU A is the HX without perforated midplates
- The failure was hypothesized to be directly related to the freeze and thaw of the water on the inside of the HX
  - Water became hydraulically locked at midplate locations and did not have a path between various sections of the HX, causing pressure to be placed on a tube



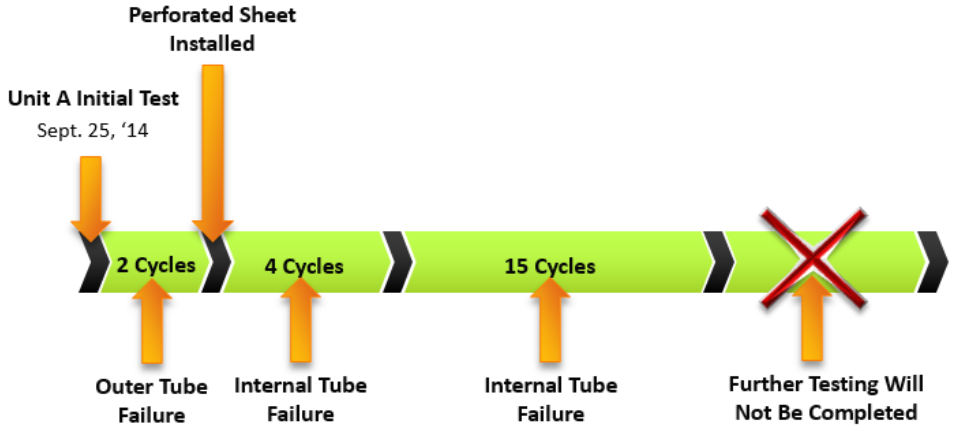


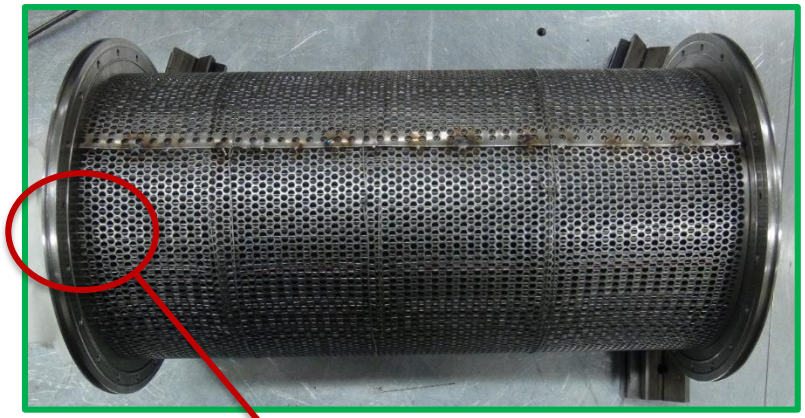
EDU A

EDU B

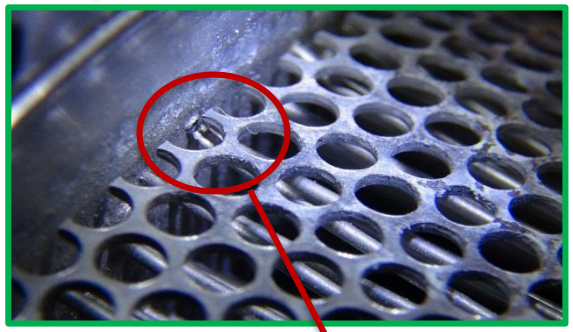


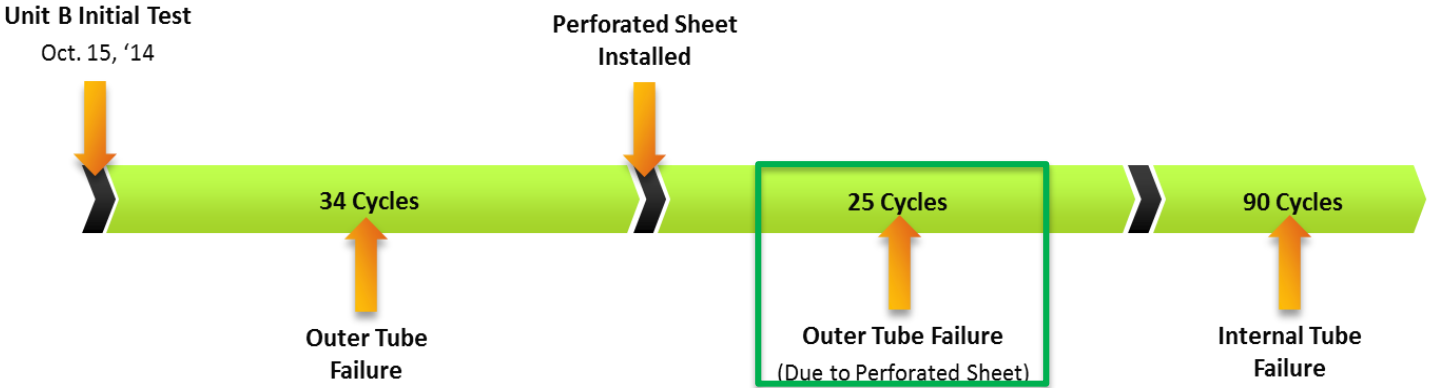
EDU A&B Testing Summary

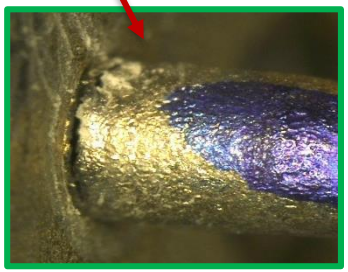




- During testing of Unit B, the bladder compressed onto the outer perforated sheet (meant to protect the outer tubes)
  - This caused the sheet to press against one of the tubes causing it to crack
- The tube was fixed and the perforated sheet was reinforced along the two edges to ensure this would not happen again







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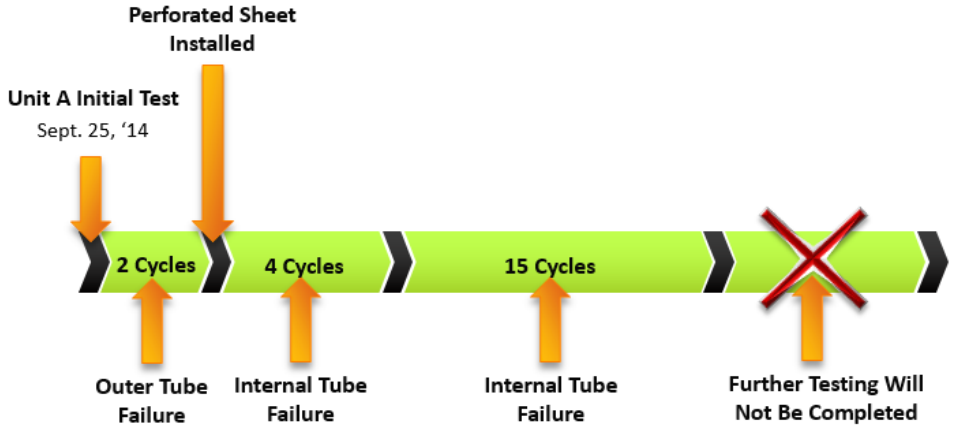
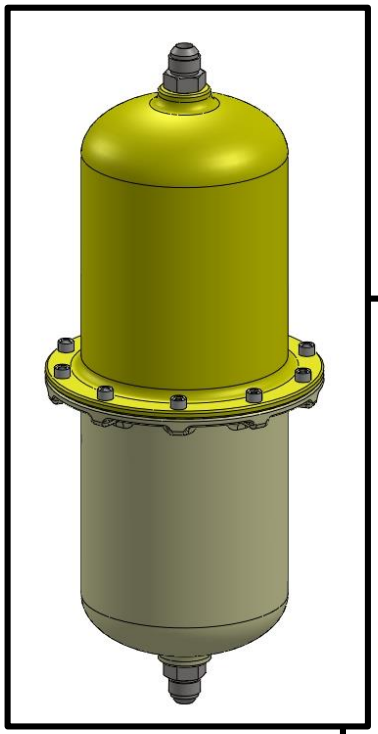
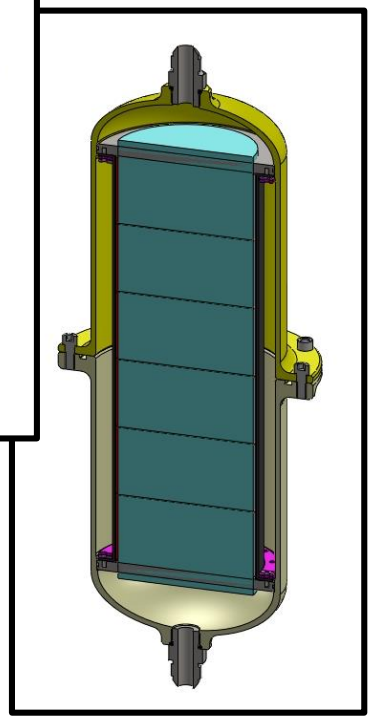
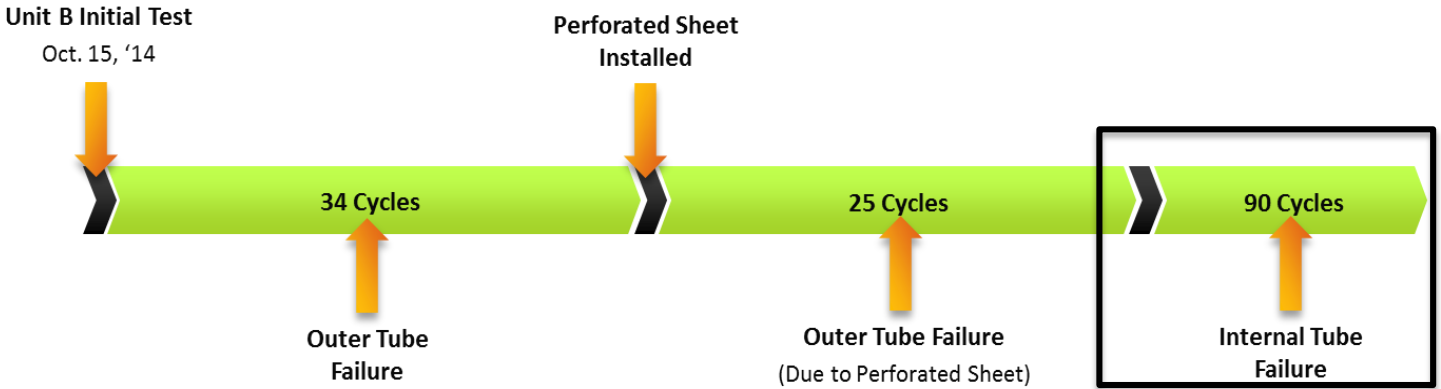






- **Completed an additional 90 cycles on EDU B before an internal tube failed**
- **Location of failure could not be clearly identified during leak checking and tube sheet deformed during these tests so no further testing could be completed**
- **Continued with sub-scale PCM design and development using EDU B midplate design and lessons learned from testing EDU A and B**



SUBSCALE DESIGN AND TESTING SUMMARY

Subscale Design

- Subscale PCM HX is a “cookie-cutter” of the full-scale unit
  - Approximately 4” in diameter and 10” long (full scale unit is 8.75” diameter and 16.1” long)
  - Designed to meet size requirements of ISS PCM HX Demonstration Loop and Orion pressure requirements
- Applied EDU A/B lessons learned to subscale unit including
  - Decreased aspect ratio
  - Use of perforated sheet and associated retaining ring
  - Use of more midplates
- Major differences between full-scale and subscale units include
  - Increased tube diameter
  - Epoxied not brazed to reduce uncertainty of braze process

“Cookie Cutter” of Full Scale Unit

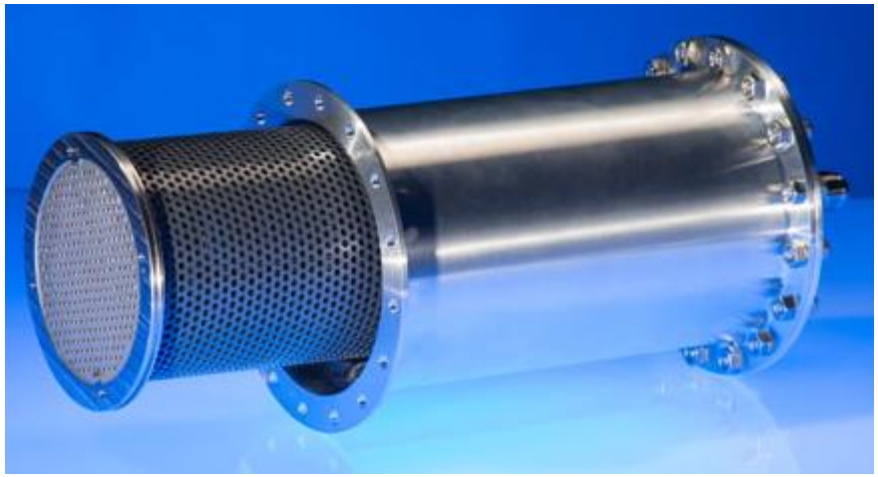
Subscale Unit Components

Characteristic	*Full-Scale Unit*	*Subscale Unit*
Outer Diameter (in)	0.042	0.058
Tube Wall (in)	0.0035	0.0058
# of Tubes	1461	324

Subscale Testing Outcomes

- Testing with approximately the same flow rate per tube area as full scale unit
  - 85 lbs/hr for subscale unit verses 235 lbs/hr for full scale unit
  - Allows for scalability between full-scale and subscale units
- No major differences noticed between full-scale and subscale freeze/thaw cycling
  - Bladder expands evenly over length of HX and perforated sheet protects HX core during thawing
- 150 successful cycle completed as of July 14th!
  - 40 favorable, 21 neutral, 89 unfavorable cycles
- 1 minor testing issue
  - During cycle 19, the water fill screw developed a very minor leak which was observed in the temperature time data.
  - O-ring grease was added to threads and o-ring and testing resumed
  - No leaks or failures since leak was fixed

Tubes Inserted into Midplate



Subscale Core Inserted Into Shell

QUESTIONS?